Tecnológico de Monterrey

Analysis and Simulation of the air defense system “Iron Dome”

Programming Languages

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Introduction

In this project I'm going to analyze the Israeli Missile air defense system better known as the “Iron Dome” in an effort to create a comprehensive adaptation and simulation using Concurrency implemented with Java.

The main objective of this simulation is to encapsulate the functionality of the “Iron Dome” and implement its main characteristics such as the basic physics involved and the behaviour of the system as a whole. This means we will not be over analyzing external factors or complications that can interfere with the system; we will focus on its programming implementation and principles based on my vision of the system.

We will be decomposing the system into its elemental components and proceed to represent them and their functionality in Java in order to create a partial simulation of how the system behaves in a concurrent paradigm.

Specifications of the Iron Dome

To begin we will first do a comprehensive summary of the Air Defense System. The Iron Dome (כִּפַּת בַּרְזֶל, *Kippat Barzel in Hebrew)* is a mobile all-weather air defense system developed by I*srael Aerospace Industries* to intercept and destroy projectiles fired from distances of 4 km to 70 km directed to populated areas.

It began its operational service on the 27th March 2011 near Beersheba, the fourth biggest metropolitan area in Israel and on the 7th of April successfully intercepted its first target. Israeli sources boast a 95% to 75% success rate and by 2014 the system had already intercepted an estimated 12,000 projectiles as part of operation Pillar of Defense, in 2021 alone it is estimated that it intercepted 90% of the rockets launched during the recent Israel-Palestine crisis.

This system operates based on missile defense batteries each with three main components:

1. **Radar.** The radar is in charge of detecting the launch of projectiles and relaying the pertinent information to the control center.
2. **Control center.** This computer unit is responsible for calculating if the detected projectile is headed for its assigned protected area and if this is the case it signals the launcher to deploy a countermeasure.
3. **Missile Launcher.** The launcher unit is responsible for holding and deploying missiles based on the calculations made by the control center.

Each missile launched is then guided by the control center to its designated target and once it has reached a position relative to the target it will explode in order to destroy it. *e.g* Iron Dome system in action

It is estimated that there's 10 of these batteries currently deployed along Israel each with 3-4 launchers holding a salvo of approximately 20 missiles each for a total of 80 missiles per battery. Every unit is mobile so its position can be relative to the system's needs thus each battery can be serviced and recharged with relative ease.

Calculations of an Air Defense System

A system such as this can involve many kinds of calculations each pertaining to the other in a very complex operation. For practical reasons in the case of our project we are going to ignore the complicated calculations that we could incur in should we try to make a functional representation of the system, instead we will be focusing on the functionality of the system as a whole and calculating the most basic physics elements.

In this representation we are going to be interacting with the projectile motion element of the system in order to encapsulate its most important feature which is the interception of another projectile, this is due to the fact that the trajectory of any projectile implements a parabola in order to maximize efficiency. The essential calculations of projectile motion are the following:

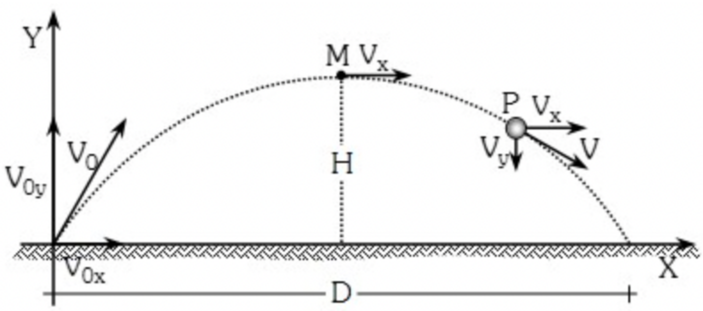
Time of flight: $Tv = 2 * Vo * Sen\theta / g$

X Position: $x = Vo * Cos\theta * t$

Y Position: $y = Vo * Sen\theta * t - \frac{1}{2}gt^2$

Maximum Height: $H = Vo^2 * Sen^2\theta / 2g$

$Vo = initial\ velocity,\ \theta = angle\ of\ launch,\ t = time,\ g = gravity$



For the purposes of this exercise we will assume that the velocity at which the projectiles are launched are constant and that other elements such as friction and wind are negligible.

We will use the projectiles time of flight in order to determine how long it will take to impact, its X and Y position will be used to determine the current position, maximum height will represent the optimal interception point as in a practical application this is the point at which the projectile will cause the least amount of damage.

The elements necessary to do these calculations will be obtained from the “radar”, then they will be passed through to the launcher that will then do the necessary operations and then it will pass the interception data to each one of the missiles.

The Iron Dome in concurrent Programming

Now that we have laid out the basics of the system as a whole we will begin a comprehensive translation to concurrent programming in Java. In order to apply a concurrent paradigm, the implementation of each element will be based on threads, some will be in contact with each other and some will be operating independently but all of them will be handled by a main.

Our program will represent one of the aforementioned batteries and the “enemy”. The battery will be composed of a “radar” handled by 1 thread, four launchers each carrying 20 missiles, every launcher will be handled by 1 thread that will in turn handle each missile.

The main will be executed and create each of the threads for its individual operation and there they will interact with one another, the “radar” thread actively tries to detect an attack from the enemy “thread” then it will relay the initial information of the enemy projectile to one of the launcher threads and consequently the launcher will create a new missile to which it will pass the calculations needed to reach the “enemy” attack. The “missile” will indicate the time and position of the interception as a statement, this process will be done for each of the 20 missiles for a maximum of 80 missiles.

The enemy thread will sporadically signal the radar thread to represent an attack and it generates the initial data (i.e angle and speed) of each attack with a randomized range, thus each simulation will be different allowing for a representation of the 90%+ accuracy rate.

This way we will be able to represent the real life model where the information is relayed by the components but also allowing for real errors.

Resulting Simulation

For the resulting simulation of the Iron Dome we can display several different values and elements of the system. Firstly we indicate the start of the system:

```
Missile defense system engaged...
Iron Dome is operational
```

Then each of the elements and the 6 threads come online:

```
Radar Operational, scanning for threats
```

```
Launcher 3 is now active
Enemy is ready to attack!!! with 74 attacks
Launcher 4 is now active
Launcher 1 is now active
Launcher 2 is now active
```

Each of these elements then starts performing their own assigned task until the main signals the attack is over:

Radar: This thread constantly checks the enemy thread in order to assess whether a launch has been made and then takes the information of the launch to then assign it to a launcher.

```
Threat detected! reported velocity: 127.92961756859692 with and angle of 39.98339354844775 degrees
Launcher 1 to intercept
```

Enemy: This thread waits randomized amounts of time to launch new attacks with randomized values, thus enabling a more wide arrange of simulations because no two simulations will be the same.

```
Enemy is ready to attack!!! with 19 attacks
```

Launcher: These 4 threads take the information passed to them by the radar, and then compute it in order to produce a “missile” with its intersection coordinates, it can do this 20 times, after it is empty the next launcher begins operating.

```
Launcher 1 firing, remaining salvo is 19
Missile 1 in the air interception coordinates: 6313.817889282577X, 103599.98826078408Y
```

The simulation will then run until the threats have ended and it will go through the aforementioned process in a concurrent manner.

Once the randomized number threats have been all handled the system and each of the threads will shutdown by parts we will see a comprehensive detail of the operation:

```
Enemy stands down
```

```
Radar shutting down...
```

```
Launcher 1 shutting down
Launcher 2 shutting down
Launcher 4 shutting down
Launcher 3 shutting down
Attack over with 56 handled threats

Process finished with exit code 0
```

Tests

https://docs.google.com/spreadsheets/d/1eNychWNwGDyvDgLaDcmt85Jl5l693VSiymwlWQmIcAo/edit?usp=sharing

Since the values change randomly with each simulation for the purposes of this project I took a sample of 15 values and with this I was able to calculate the average interception rate of the simulation to 97% thus fulfilling the objective of a system that's more than 90% efficient like the real Iron Dome.

Conclusion

The objective of this project was to demonstrate a system implemented in concurrency and needles to say that objective was fulfilled. The resulting program showed a reasonable representation of the Iron Dome interception system and the way information was relayed and handled throughout the simulation properly represented the way we can implement Threads to handle different aspects of the system in real time.

The errors contained within the simulation also help demonstrate the imperfection of real life applications, since in the world error can occur with many aspects of the system thus compromising its functionality, but ultimately we were able to also maintain a very high success rate which would be the ideal scenario.

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